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Baryon-baryon {8} ⊗ {8}-channels interactions

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The extended-soft-core model ESC08 is presented. The ESC-models are at present the most complete meson-exchange models for the baryon-baryon interactions. The ESC-model describes the nucleon-nucleon (NN), hyperon-nucleon (YN), and hyperon-hyperon (YY), in terms of meson-exchanges using (broken) SU$(3)_f$-symmetry. In this approach to baryon-baryon (BB) the dynamics is derived from (i) one-boson-exchanges (OBE), (ii) two-meson-exchanges (TME), and (iii) meson-pair-exchanges (MPE), (iv) gluon-exchanges in the form of the pomeron and odderon potentials, and (v) quark-core effects. In the OBE-sector, special features are: (a) the inclusion of a zero in the scalar- and axial- meson form-factors, (b) the odderon-exchage representing the exchange of the odd-number gluons-exchange, whereas the pomeron represents the even-number gluon-exchange, and (c) special pronounced effects of the appearance of forbidden six-quark configurations. With these ingredients a rather flexible dynamical framework is constructed. Namely, it appeared feasible to keep the parameters of the model in reasonable accordance with the predictions of the $^3P_0$ quark-pair-creation model (QPC), although in ESC08a,b,c an admixture of $^3S_1$ quark-pair creation is present. This is the case for the meson- and meson-pair-baryon coupling constants and the $F/(F+D)$-ratio's as well.
The NN, YN, and YY results for this model are excellent. This is marked in particularly by the NN-results, namely $\chi^2_{p.d.p.} = 1.08$ for ESC08a,b,c. Also, we improved the ΛN spin-orbit interaction greatly by the inclusion of (a) the Brown, Downs, and Iddings anti-symmetric spin-orbit potentials, and (b) new corrections to the MPE-potentials. Also, the special quark-core effects provide extra repulsion in the $\Sigma^+ p(^3S_1, T = 3/2)$- and $\Sigma N(^1S_0, T = 1/2)$-channels, although the strength is constrained by SU(3) symmetry and the $\Sigma^+ p$ experimental X-sections. In the S=-2 sector the $\Lambda\Lambda$-interaction is weak, which is in accordance with the NAGARA-event. Furthermore, in the $\Xi N(^3S_1, I = 1)$ there occurs a "strange-deuteron" D* with binding-energy $E_B^* \approx 2.0 - 1.5$ MeV.
A very notable consequence of the MPE-vertices are the related three-body forces (TBF). In this conference we report on the predictions of these TBF's for (i) the triton binding energy, and (ii) the charge-symmetry-breaking (CSB) effects. The first results are encouraging.

KEYWORDS: 13.75.Cs, 12.39.Pn, 21.30.-x, . . .

1. Introduction

This report is an update of the presentation at HYP-X [1] of the results with the Extended-soft-core (ESC) models. In [1] the ESC08a and ESC08b models [2] have been discussed. Here, we review the ESC08c-model [3–5], which is the most recent and complete version of the ESC08-model. In addition to the scattering properties and G-matrix results, also some results on the implicated (parameter free) three-body forces (TBF) are described. These TBF's are a consequence of the meson-pair couplings to the baryons as determined by the fit to the baryon-baryon (BB) scattering data as well as by the G-matrix analysis of the S=-1,-2 hypernuclei.

The ESC-model describes the low-energy nucleon-nucleon (NN), hyperon-nucleon (YN), and hyperon-hyperon (YY), in terms of meson-exchanges using (broken) SU$(3)_f$-symmetry. The baryon-

baryon (BB) dynamics is derived from (i) one-boson-exchanges (OBE), (ii) two-meson-exchanges (TME), and (iii) meson-pair-exchanges (MPE), (iv) gluon-exchanges in the form of the pomeron and odderon potentials, and (v) quark-core effects. A further special feature is the inclusion of a zero in the scalar- and axial- meson form-factors, which reflect the distinction w.r.t. the pseudoscalar and vector mesons. The latter correspond to quark-antiquark s-wave and the former to p-wave states.
The distinguishing features between the ESC04 models [6–8] and the ESC08c model are: (a) the *odderon*-exchange representing the exchange of the odd-number gluons, whereas the *pomeron* represents the even-number gluon-exchange, (b) special pronounced effects of the appearance of forbidden six-quark configurations, (c) the inclusion for the axial-vector-mesons with $J^{PC} = 1^{++}$ besides the $\gamma_\mu\gamma_5$- also the derivative coupling, (d) inclusion non-local spin-spin and tensor potentials in the pseudoscalar potentials, both in NN-, YN-, and YY-channels. W.r.t. (a) we add that the odderon corresponds to a color singlet n-gluon exchange, with odd $n = 3, 5, ...$ and which has a vector-exchange character [9]. This is in contrast to the pomeron which is a scalar.
Important recent developments have been taken into consideration. First, the inclusion of a density dependent universal repulsion for the BB-interaction in a nuclear medium [10] in the multi-pomeron interpretation [11]. This brings about three good things: (i) great improvement in nuclear saturation, (ii) stiffening of the equation of state (EOS), giving a realistic neutron-star mass, (iii) and improving the well-depth's U_Λ, U_Σ. Recently we ascribe this repulsion to multi-gluon exchange in the form of multi-pomeron exchange, which is clearly universal due to the fact that the gluons are "flavor-blind". Application to nucleus-nucleus scattering and the so-called "hyperon-puzzle" [12] has been succesful. Second, the observations of Ξ hypernuclei [13]. The information on the U_Ξ via the G-matrix calculations is an important input in order to settle the final parameters.

The main framework for the BB-interactions is unchanged and given by the ESC-potentials from OBE-, TME-, and MPE-exchanges. In our experience, this has led to a rather flexible dynamical system that allows the guidance by certain theoretical constraints, while giving very satisfactory fits to the data. An important guidance chosen are the couplings and $F/(F + D)$-ratio's as suggested by the QPC-model [14]. Here, we employ the constituent quark model (CQM) in SU(6)-version of [15]. In particularly, the F/(F+D)-rations for the meson-pair vertices are taken as fixed by the QPC-model, avoiding thereby many arbitrary parameters.

Chiral-symmetry is assumed to be realized non-linearly in nature, see e.g. [16]. The non-linearity occurs in the pionic-sector and is included approximately in the form of: (1) two-pion exchange (TPEP), and (2) $\pi\pi$-pair exchange in all possible states. For the other mesons (vector, scalar, axial-vector) only SU(3)-flavor invariance is required.

We emphasize that the NN and YN low and intermediate energy data were fitted in a unified manner, i.e. simultaneously with single sets of parameters. The first step in this procedure is the fit of the NN-data [3] leading to a NN-model, where we reached $\chi^2_{p.d.p.} = 1.08$. The second step is fitting simultaneously the NN- and the YN-data for S=-1,-2, taking into account G-matrix information from $\Lambda-, \Sigma-$, and Ξ-hypernuclei calculations. Last but not least, the constraint of the absence of bound states for the S=-1 YN-channels are applied. The results/predictions for the $S = -2$-sector were (preliminary) published in [4]. We obtained typically for the YN-data $\chi^2_{p.d.p.} \approx 1.08$. The set of 52 YN-data was also fitted succesfully, while having no bound states. This set comprises the usual standard set of 35 data employed in the Nijmegen work on YN [17], plus the recently measured $\Sigma^+ p$ X-sections of the KEK-PS E289 experiment [18, 19].

In the ESC04-model the ΛN spin-orbit was much too large. For the solution of this ΛN spin-orbit problem we include in the ESC08 models: (i) the Brown, Downs, and Iddings [20] terms for the $S \neq 0$-exchanges with K, K*, κ, and (ii) similar terms in MPE-potentials. The inclusion of these novel ESC-potentials brings the spin-orbit much more in agreement with experiments [21].

All Nijmegen soft-core models seem to lack enough repulsion for giving a (very) strong repulsive U_Σ [22] in ${}^{9}_{\Sigma}$Be and ${}^{28}_{\Sigma}$Si. The main reason seems the limitations coming from SU(3)-symmetry

Table I. Meson and meson-pair table ESC08-model. The SU(3)$_f$-irreps are denoted by $\{\mu\}$.

$^{2S+1}L_J$	J^{PC}	$I=1$	$I=0$	$I=1/2$	$\{\mu\}$
$^1S_0$	0^{-+}	$\pi(140)$	$\eta(495), \eta'(958)$	K(495)	$\{8\}\oplus\{1\}$
$^3S_1$	1^{--}	$\rho(760)$	$\omega(783), \phi(1019)$	$K^*(892)$	$\{8\}\oplus\{1\}$
$^3P_0$	0^{++}	$a_0(980)$	$\epsilon(760), S^*(993)$	$\kappa(900)$	$\{8\}\oplus\{1\}$
$^3P_1$	1^{++}	$a_1(1270)$	$D(1285), E(1420)$	$K_1(1400)$	$\{8\}\oplus\{1\}$
$^1P_1$	1^{+-}	$b_1(1235)$	$h_1(1170), h_1'(1380)$	$K_{1B}(1400)$	$\{8\}\oplus\{1\}$
$^3P_0$	0^{++}	—	$\pi\pi, \eta\eta$, K$\bar{\rm K}$	—	$\{1\}$
$^3P_0$	0^{++}	$\pi\eta$, K$\bar{\rm K}$, ...	$\pi\pi, \eta\eta$, K$\bar{\rm K}$	πK, ηK,	$\{8_s\}$
$^3S_1$	1^{--}	$\pi\pi$, K$\bar{\rm K}$, ...	—	πK, ηK	$\{8_a\}$
$^3P_1$	1^{++}	$\pi\rho$, K$\bar{\rm K}^*$, ...	K$\bar{\rm K}^*$, ..	Kρ, πK*	$\{8_a\}$
$^3P_1$	1^{++}	$\pi\sigma$, K$\bar{\kappa}$, ...	K$\bar{\kappa}$, ..	Kσ, $\pi\kappa$	$\{8_a\}$
$^3P_1$	1^{+-}	$\pi\omega$, K$\bar{\rm K}^*$, ...	K$\bar{\rm K}^*$, ..	Kρ, πK*	$\{8_s\}$

and the experimental Σ^+p X-sections. Namely, SU(3) links the $\Sigma^+p(^1S_0)$ to the $pp(^1S_0)$ limiting the $\Sigma^+p(^3S_1)$-phase shift. Futhermore, the OBE spin-spin force from the pseudoscalar and vector potentials changes sign in the interior. To analyze this problem more deeply, it is natural to look for some change in the short-range potentials. The work on the flavor(F) and spin(S) SU(6)$_{f\sigma}$ quark-cluster model (QCM) of BB-interactions [23–25], seemed to indicate that much stronger repulsion in the Σ^+p spin-triplet channel could result because of the Pauli-forbidden SU(6)-irrep [51]. Indeed, the $(0s)^6$ configuration has an exceptional large weight in the SU(3)$_f$-irreps $\{10\}$ and $\{8_s\}$. So, in particularly for the $\Sigma^+p(^3S_1, T=3/2)$- and $\Sigma N(^1S_0, T=1/2)$-channels. For the other channels the weights are about 50%. Therefore, we represent the short-range repulsion due to two-gluon-exchange and the average effects of the forbidden [51] configuration by the pomeron, and effectuate the exceptional repulsion in specific BB-channels due to the SU(6)$_{f\sigma}$-irrep [51] by giving here the pomeron an enhancement factor. This procedure ameliorates the lack of a strong repulsion in these specific YN-channels, but cannot solve this problem with the Σ-hypernuclei. A possibility for the later is the occurrence of repulsion from the ΣNN three-body force.

In the simultaneous NN+YN fitting, apart from the excellent NN-fit, the $S=-1,-2$-sectors are also fitted succesfully. We obtained for YN $\chi^2_{p.d.p.} = 1.180$, 1.135, and 1.08 for respectively ESC08a, ESC08b, and ESC08c.

The meson dynamical contents of the ESC08-model is best illustrated by looking at Table I. The quantum numbers $^{2S+1}L_J$ refer to those of the $q\bar{q}$ ground-states corresponding to the mesons. The lower part of this table shows the meson-pair exchange contents. Here, the $q\bar{q}$ quantum numbers refer to the dominant heavy-boson contributions to the pair-vertices. In ESC04 all these exchanges were also included, except for the axial-vector mesons of the second kind having $J^{PC}=1^{+-}$. Besides the OBE- and MPE-potentials, also included are the uncorrelated two-pseudoscalar exchanges (TPE), and the diffractive pomeron/odderon potentials, whose quantum numbers are $0^{++}/1^{--}$.

The contents of this paper is as follows. In section 2 we describe the new short-range phenomenology based on the SU(6)$_{f\sigma}$ quark-model and pomeron/odderon-exchange. In section 3 we review the

Table II. Weights SU(6)$_{f\sigma}$-irreps in the SU(3)$_f$-irreps.

$V_{\{27\}}$	=	$\frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$	,	$V_{\{1\}}$	=	$V_{[33]}$,
$V_{\{10^*\}}$	=	$\frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$	,	$V_{\{10\}}$	=	$\frac{8}{9}V_{[51]} + \frac{1}{9}V_{[33]}$,
$V_{\{8_a\}}$	=	$\frac{5}{9}V_{[51]} + \frac{4}{9}V_{[33]}$	,	$V_{\{8_s\}}$	=	$V_{[51]}$.

meson and meson-pair contents of ESC08. In section 4 we review the connection with the QPC-model and with the CQM. In section 5 we give and discuss the hyperon-nucleon/hyperon results of ESC08. In section 6 the CSB in A=4 Λ-hypernuclei from the meson-pair vertices is discussed. In section 7 we close with conclusions and outlook.

2. Short-range Phenomenology

As is well known the BB-channels can be expressed in terms of the flavor SU(3)$_f$-irreps, because $\{8\} \times \{8\} = \{1\} \oplus \{8_s\} \oplus \{8_a\} \oplus \{10\} \oplus \{10^*\} \oplus \{27\}$. In terms of the SU(6)$_{f\sigma}$-irreps these irreps can be expressed, see e.g. [2, 4], as linear combinations of the Pauli ”allowed” [3,3]- and ”forbidden” [5,1]-irrep, which is given in Table II. [2, 4], So, we see that the [51]-irrep has a dominant large weight in the {10}- and $\{8_s\}$-irrep, which gives an argument for the presence of an exceptionally strong Pauli-repulsion in these SU(3)$_f$-irreps. In ESC08 we implement these features by adapting the pomeron strength in the irreps {10} and $\{8_s\}$, notably in the $\Sigma^+ p(^3S_1, T = 3/2)$ and $\Sigma N(^1S_0, T = 1/2)$ channels. One novel feature of ESC08 is that the short-range repulsion gets non-meson exchange contributions from (i) (multiple) gluon-exchange, and (ii) quark-core effects due to the appearance of the Pauli-forbidden six-quark irrep [51]. The pomeron is a phenomenological representation of n-gluon exchange, with even $n = 2, 4, ...$ Moreover, it also takes care of the average/universal effect of the [51]-irrep. Furthermore, we enhance the pomeron coupling for the channels with an exceptional large component in the [51]-irrep.

3. Mesons, Meson-pairs, Coupling- and Cut-off-parameters

In Table III we show the couplings obtained in a first NN⊕YN fit for the ESC08a solution. The (rationalized) coupling constants and $F/(F + D)$-ratio’s are given in Table III. The f_η was not fitted but computed via meson-mixing angle θ_m and SU(3)-relations. The same for the couplings of the $\phi, S^*(993), D(1285)$, and $h(1170)$ meson. The gaussian cut-off parameters are $\Lambda_P(I = 1, 0) = 1056.1$ MeV, $\Lambda_V(I = 1) = 695.7$ MeV, $\Lambda_V(I = 0) = 758.6$ MeV, $\Lambda_S(I = 1) = 994.9$ MeV, $\Lambda_S(I = 0) = 1113.6$ MeV, $\Lambda_A(I = 1, 0) = 1051.8$ MeV, $\Lambda_B(I = 1, 0) = 1056.1$ MeV.
The pomeron and odderon have I=0, being even/odd-gluon exchange. The mass of the odderon is fitted as $m_O = 273.4$ MeV, and that of the pomeron became $m_P = 220.5$ MeV. The pomeron coupling is $g_P = 3.582$, and those for the odderon are $g_O = 4.636$, $f_o = -4.760$. The enhancement factor for the pomeron-coupling in the waves $\Sigma^+ p(^3S_1, I = 3/2)$ and $\Sigma N(^1S_0, I = 1/2)$ is $F_{[51]} = 1.275$, making the quark-core repulsion about 1/3 of the strength of the pomeron.

We note in Table III that the parameters for the vector and scalar mesons are rather similar. In the next paragraph this is explained by the quark-antiquark creation process. For the meson-pair couplings, see [3].

Table III. ESC08: Meson-couplings and $F/(F+D)$-ratio's.

J^{PC}	$I=0$		$I=1$		$F/(F+D)$		$\theta_{mix}(degr.)$	
0^{-+}	$f_{\eta'}$ =	0.231	f_π =	0.269	α_P =	0.365	θ_P =	-13.00
1^{--}	g_ω =	3.457	g_ρ =	0.645	α_V^e =	1.00	θ_V =	38.70
	f_ω =	-0.858	f_ρ =	3.774	α_V^m =	0.472		
0^{++}	g_ϵ =	4.146	g_δ =	0.585	α_S =	1.00	θ_S =	35.26
1^{++}	$g_{f_1'}$ =	–0.761	g_{a_1} =	–0.790	α_A =	0.312	θ_A =	50.00
	$f_{f_1'}$ =	–0.447	f_{a_1} =	–0.819	α_A' =	0.312		
1^{+-}	$g_{f_1'}$ =	–0.300	g_{b_1} =	–1.809	α_B =	0.40	θ_B =	35.26

4. Constituent Quark-model and ESC

The quark-pair creation (QPC) model explains nicely the BBM-coupling constants. In Table IV shows the buildup of these couplings by the ${}^3S_1$ and ${}^3P_0$ quark-pair creation mechanisms, where the latter is dominant by a factor 2 [26]. The calculation of this table uses the constituent quark model (CQM) in the SU(6)-version of Ref. [15]. Since this calculation uses implicity the coupling of the mesons to the quarks, it defines the QQM-vertex. Then, OBE-potentials can be derived by folding meson-exchange with the quark wave functions of the baryons. At the baryon level the vertices have in Pauli-spinor space the structure

$$\begin{aligned}
\bar{u}(p',s')\Gamma u(p,s) &= \chi_{s'}^{\prime\dagger}\left\{\Gamma_{bb}+\Gamma_{bs}\frac{\boldsymbol{\sigma}\cdot\mathbf{p}}{E+M}-\frac{\boldsymbol{\sigma}\cdot\mathbf{p}'}{E'+M'}\Gamma_{sb}-\frac{\boldsymbol{\sigma}\cdot\mathbf{p}}{E+M}\Gamma_{ss}\frac{\boldsymbol{\sigma}\cdot\mathbf{p}'}{E'+M'}\Gamma_{sb}\right\}\chi_s \\
&\equiv \sum_l c_{BB}^{(l)}\left[\chi_{s'}^{\prime\dagger}O_l(\mathbf{p}',\mathbf{p})\chi_s\right](\sqrt{M'M})^{\alpha_l}\ \ (l=bb,bs,sb,ss).
\end{aligned}$$

This expansion is general and does not depend on the internal structure of the baryon. A similar expansion can be made on the quark-level, but now with quark masses m_Q and coefficients $c_{QQ}^{(l)}$. It appears that in the CQM, i.e. $m_Q = M_B/3$, the QQM-vertices can be chosen such that the ratio's $c_{QQ}^{(l)}/c_{BB}^{(l)}$ are constant for each type of meson [27]. Then, by scaling the couplings these coefficients can be made equal. (Ipso facto this defines a meson-exchange quark-quark interaction.) This shows that the use of the QPC-model is consistent with the 1/M-expansion.

5. S=-1,-2 Hyperon-Nucleon/Hyperon: ESC08

The U_Λ for the ESC08a,b models has been discussed in [2]. From Table V that for ESC08c$^+$, where the MPP repulsion is included, the attraction is somewhat larger than for ESC08a,b. Fig. 1 shows that the energy spectra are nicely reproduced. As pointed out in [2] the G-matrix potential is different from a Wood-Saxon, which explains the difference with the well-depth $U_{WS} \approx 30$ MeV.

In HYP06 [28, 29] we discussed the ESC06d/ESC06d*-models, where the heavy boson nonets with all masses above 1 GeV/c^2 were studied. A main motive for ESC06 was to look for the possibility

Table IV. SU(6)-breaking in coupling constants, using (56) and (70)-irrep mixing with angle $\varphi = -22^o$ for the $^3P_0$- and $^3S_1$-model. Gaussian Quark-gluon cut-off $\Lambda_{QQG} = 986.6$ MeV. Ideal mixing for vector and scalar meson nonets. For pseudoscalar- and axial-nonets the mixing angles are -13^0 and $+50.0^o$ respectively, imposing the OZI-rule. Here, $\Lambda_{QPC} = 255.0$ MeV, $\gamma(\alpha_s = 0.30) = 2.19$ etc. The weights are A=0.697 and B=0.303 for the $^3P_0$ and $^3S_1$ respectively. The values in parentheses in the column QPC denote the results for $\varphi = 0^o$.

Meson	$r_M[fm]$	γ_M	$^3S_1$	$^3P_0$	QPC	ESC08c
$\pi(140)$	0.30	5.51	$g = -2.74$	$g = +6.31$	3.57 (3.77)	3.65
$\eta'(957)$	0.70	2.22	$g = -2.49$	$g = +5.72$	3.23 (3.92)	3.14
$\rho(770)$	0.80	2.37	$g = -0.17$	$g = +0.80$	0.63 (0.77)	0.65
$\omega(783)$	0.70	2.35	$g = -0.96$	$g = +4.43$	3.47 (3.43)	3.46
$a_0(962)$	0.90	2.22	$g = +0.19$	$g = +0.43$	0.62 (0.64)	0.59
$\epsilon(760)$	0.70	2.37	$g = +1.26$	$g = +2.89$	4.15 (4.15)	4.15
$a_1(1270)$	0.70	2.09	$g = -0.13$	$g = -0.58$	-0.71 (-0.71)	-0.79
$f_1(1420)$	1.10	2.09	$g = -0.14$	$g = -0.66$	-0.80 (-0.81)	-0.76

Table V. Partial wave contributions to $U_\Lambda(\rho_0)$

	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	sum
ESC04d	–13.6	–26.6	3.2	–0.2	0.9	–6.4	–1.4	–44.1
ESC08a	–12.7	–22.2	3.0	0.1	1.4	–3.6	–1.6	–35.6
ESC08b	–12.3	–19.7	2.7	–0.2	1.5	–4.2	–1.7	–34.0
ESC08c	–13.1	–26.5	2.4	0.1	1.1	–3.1	–1.6	–40.8
ESC08c$^+$	–12.6	–25.4	2.9	0.3	1.6	–2.1	–2.3	–37.6

to increase the short-range repulsive part of the potential in the $\Sigma^+p(^3S_1)$-channel. That was achieved, but because this came from the heavy pseudoscalar nonet it led to a very large $\Sigma^+p(^1P_1, I = 3/2)$-phase. In the ESC08-model such an extra epulsion is realized through the $F_{[51]}$-parameter in this channel. For ESC08a the scattering length is $a(^3S_1, \Sigma^+p) = 0.76$ fm, and the phase shift at 900 MeV/c is $\delta(\Sigma^+p,^3S_1) = -65^o$. In ESC08c the scattering length is $a(^3S_1, \Sigma^+p) = 0.61$ fm, and the phase shift at 900 MeV/c is $\delta(\Sigma^+p,^3S_1) = -49^o$. As has been pointed out by Dabrowski [22] unlike ESC04, the NHC-F model [30] is succesfull for the BNL $^9_\Sigma$Be-experiment. Now, the ESC08 $^1S_0$ phase is very similar to that in NHC-F model, and also the $^3S_1$-phase at $p_{Lab} = 900$ MeV/c is like that in NHC-F and QCM [25].

This is reflected in the well depths, see Table VI. We have now $U_\Sigma = -1.2$ MeV in ESC06d, $U_\Sigma = +8.2$ in ESC06d* [1]. Whereas, $U_\Sigma = +13.4, +20.34$ MeV in ESC08a, respectively ESC08b. This illustrates the effect of the exceptional repulsion from the quark-core in the $\Sigma^+p(^3S_1, T = 3/2)$-wave. In ESC08c, as shown in Table VI, the MPP is necessary to produce a sizeable repulsion for

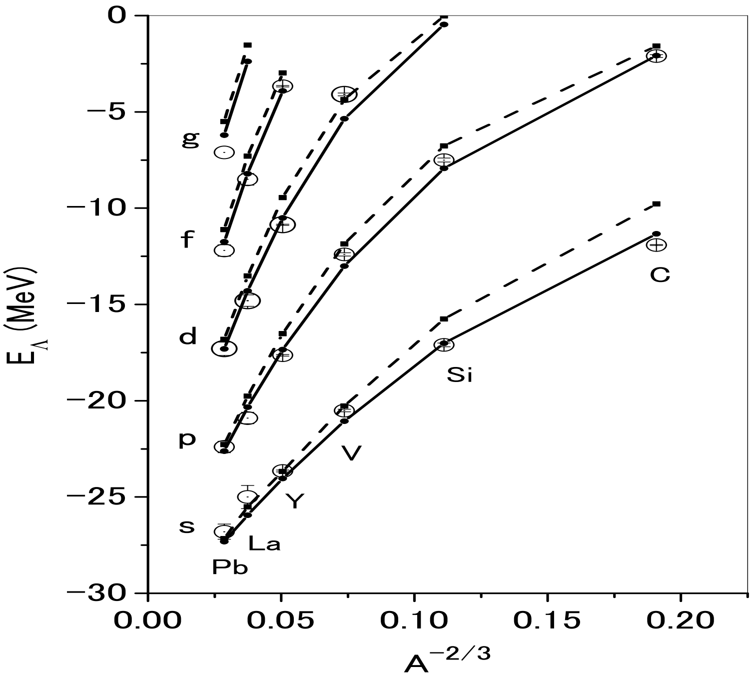

Fig. 1. Energy spectra of $^{13}_{\Lambda}$C, $^{28}_{\Lambda}$Si, $^{51}_{\Lambda}$V, $^{139}_{\Lambda}$Y, and $^{208}_{\Lambda}$Pb are given as a function of $A^{-2/3}$, A being mass numbers of the core nuclei. Solid (dashed) lines show calculated values by the G-matrix folding model derived from ESC08c^{+} (ESC08c). Open circles denote the experimental values taken from Ref. [32]

Table VI. Partial wave contributions to $U_\Sigma(\rho_0)$

model		$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Σ
ESC08a	$T = 1/2$	11.3	–23.9	2.3	1.7	–6.2	–1.4	–0.7	
	$T = 3/2$	–11.7	44.8	–7.2	-1.7	6.5	0.2	–0.2	+13.4
ESC08b	$T = 1/2$	10.3	–26.2	2.5	2.2	–7.9	–1.7	–0.8	
	$T = 3/2$	–10.6	52.7	–6.2	-2.0	7.4	0.8	–0.1	+20.3
ESC08c	$T = 1/2$	11.1	–22.0	2.4	2.1	–6.1	–1.0	–0.7	
	$T = 3/2$	–12.8	30.7	–4.8	-1.8	6.0	–1.4	–0.2	+1.4
ESC08c+	$T = 1/2$	11.1	–20.4	2.6	2.1	–5.8	–0.6	–0.8	
	$T = 3/2$	–11.9	31.8	–4.2	-1.6	6.4	–0.4	–0.6	+7.9

U_Σ. (In ESC08 we have not included the possible effect of the nuclear medium on the vector-meson masses, as in [7].

The channels with strangeness S=-2 are for the $\Lambda\Lambda(^1S_0)$-channel similar to ESC04d, for which $\Delta B_{\Lambda\Lambda} \approx 0.80$ MeV, which is nicely in accordance with the Nagara event [31]. The $\Lambda\Lambda$ low-energy parameters in ESC08a are $a_{\Lambda\Lambda}(^1S_0) = -0.85$ fm and $r_{\Lambda\Lambda}(^1S_0) = 5.13$ fm. In contrast to ESC07 [33], the Ξ well-depths are in ESC08 very attractive, in particlarly for ESC08b. For ESC08a the well-depth is similar to that of ESC04d with $U_\Xi = -18.7$ MeV. However, this time the attraction is produced in the 'deuteron-like' S=-2-channel, which is more satisfying. In ESC08b and ESC08c the existence of a S=-2 deuteron D* is predicted, belosw the ΞN threshold. In ESC08c the binding energy is $B_E = 1.56$

Table VII. Partial wave contributions to $U_\Xi(\rho_0)$

model		$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	U_Ξ	Γ_Ξ
ESC08a	$T=0$	6.0	–1.0	–0.3	–2.6	1.3	–0.9		
	$T=1$	8.5	–28.0	0.6	0.4	–3.7	–0.6	–20.2	6.4
ESC08b	$T=0$	6.6	0.6	–0.4	–1.6	0.5	–0.7		
	$T=1$	9.0	–42.2	0.7	–0.1	–3.6	–1.1	–32.4	2.6
ESC08c	$T=0$	1.4	R–8.0	–0.3	1.8	1.4	–2.1		
	$T=1$	10.7	–11.1	1.1	0.7	–2.6	–0.0	–7.0	4.5

MeV and is a member of the {10*}-decuplet like the deuteron $D = np(^3S_1, I = 0)$. For both D and D* strong tensor forces are responsible. The experimental search for BB bound states in the mass range 2.1-2.5 GeV/c^2 was negative [34]. To this we remark that in the ESC08 model the existence of the D*-state is rather necessary to produce an attractive Ξ-nucleus potential as indicated by [35].

The very recently discovered Ξ-hypernuclei [13] through the observation of Λ twin states in the reactions

$$\begin{aligned} &(I) && \Xi^- + {}^{12}\mathrm{C} \rightarrow {}^{9}_{\Lambda}\mathrm{Be} + {}^{4}_{\Lambda}\mathrm{H}, \\ &(II) && \Xi^- + {}^{12}\mathrm{C} \rightarrow {}^{9}_{\Lambda}\mathrm{Be}^* + {}^{4}_{\Lambda}\mathrm{H}, \\ &(III) && \Xi^- + {}^{14}\mathrm{N} \rightarrow {}^{10}_{\Lambda}\mathrm{Be}^* + {}^{5}_{\Lambda}\mathrm{He}, \end{aligned}$$

indicated that U_Ξ is shallower than in ESC08a,b. Detailed calculations in [5] showed that one can give a consistent interpretation of the emulsion events (I), (II), and (III) using the G-matrix interaction derived from ESC08c.

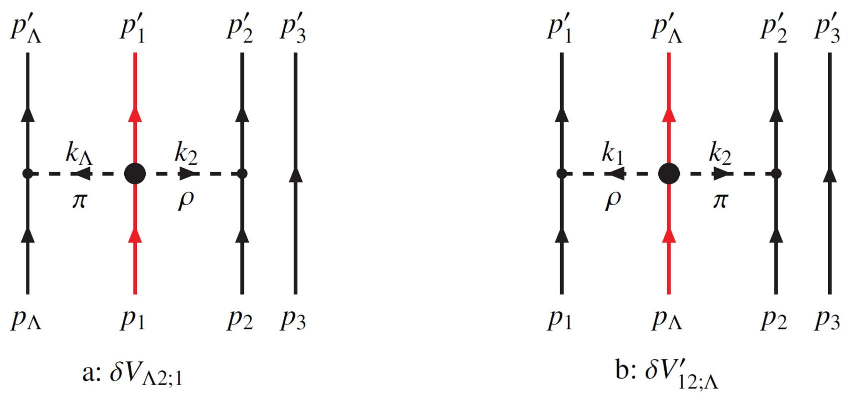

Fig. 2. *The Born-Feynman diagrams for $V_{\Lambda 2;1}, V_{12;\Lambda}$*

6. ESC08 Three-body forces

As mentioned above, there are two kinds of TBF's in the ESC-model. Namely the universal repulsion from multi-pomeron eschange (MPP) and the TBF coming from the meson-pair vertices.

For the MPP we refer to the Ref's [12]. Here we report on the first (preliminary) results for the triton and CSB in the A=4 hypernuclei. In Fig. 2 an example is given of the diagram showing a contribution of the $(\pi\rho)$-pair coupling to the CSB in the A=4 Λ-hypernuclei.

The CSB from the OBE-potentials in the ESC-models is very small, in contrast to NSC89. The difference is due to $\alpha_s = 1.0$, whereas for NSC89 $\alpha_S = 1.28$. Therefore, we investigate the possible contribution from the CSB from the TBF. To estimate the contribution of the meson-pair induced TBF w.r.t. the CSB $\delta B_\Lambda = B_\Lambda(^4_\Lambda\mathrm{He}) - B_\Lambda(^4_\Lambda\mathrm{H})$ we used the wavefunction of [36]. The recent MAMI result [37] gives $\Delta B_\Lambda = 280$ keV, which is close to $\Delta B_\Lambda = 0.29 \pm 0.06$ MeV [38]. Table VIII indicates that the TBF from the meson-pairs could be succesful for CSB.

Table VIII. MPE contributions to $\Delta B_\Lambda = B_\Lambda(^4_\Lambda He) - B_\Lambda(^4_\Lambda H)$ in keV are shown.

J^{PC}	$\{\mu\}$	Meson-pair	$\Delta B_\Lambda(11)$	$\Delta B_\Lambda(12)$	$\Delta B_\Lambda(22)$	ΔB_Λ
0^{++}	$\{8\}_s$	$(\pi\pi)_0$	-15.44	-7.71	-5.10	-35.96
		$(\pi\eta)_1$	+4.56	+2.20	+1.35	+10.31
		$(\eta\eta)$	—	—	—	
1^{--}	$\{8\}_a$	$(\pi\pi)_1$	-3.19	-1.19	-0.36	-5.93
1^{++}	$\{8\}_a$	$(\pi\rho)_1$	+51.46	+15.95	+3.95	+87.31
1^{++}	$\{8\}_a$	$(\pi\sigma)_1$	+63.40	+30.94	+19.50	+144.78
		$(\eta\sigma)$	—	—	—	
1^{+-}	$\{8\}_s$	$(\pi\omega)_1$	+11.44	+4.71	+2.22	+23.08
		$(\pi\rho)_0$	+1.49	+0.63	+0.32	+3.05
		$(\eta\phi)$	—	—	—	
0^{++}	$\{1\}$	3P, 4P	—	—	—	
Total			+113.71	+45.54	+21.93	+226.69

7. Conclusions and Outlook

The prospects for a completely satisfactory ESC-description of the BB-channels for S=0,-1,-2 are rather good. For nuclear saturation, the EoS, neutron matter, B_Λ, and CSB three-body forces are definitely required.
The extension from ESC04 to ESC08 solved the quest for more repulsion in the $\Sigma N(I = 3/2, ^3S_1)$ and the $\Sigma N(I = 1/2, ^1S_0)$ states, and attraction for the Ξ-nucleus interaction. We emphasize that the introduction of the quark-core effects will not influence strongly the BB-channels in the S=-2-sector. This, because here the $SU(6)_{f\sigma}$-irrep [51] does not occur with large weights. So, the attraction in ESC08 in the $\Xi N(^3S_1, I = 1)$, which is $\{10^*\}$, is not destroyed by an exceptional Pauli-repulsion. The realization of solutions in fitting all the available BB-data, keeping the good features already realized and at the same time providing a sizeable Ξ-nuclear attraction has largely been achieved with the ESC08-models. This opens prospects for realistic predictions for the S=-3,-4 systems.
For the nuclear saturation, EoS, neutron matter, B_Λ, and CSB i three-body forces are definitely required.

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